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Prepared for:

Department of Energy, Mines and Resources
Transportation Energy Branch
460 O'Connor Street
Ottawa, Ontario

Prepared by:

Applied Physics and Engineering Division
B.C. Research
3650 Wesbrook Mall
Vancouver, B.C.
V6S 2L2

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CNG COMPRESSOR OPERATIONS MONITORING

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DISCLAIMER

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ABSTRACT

The operating performance characteristics of seven (six different types) CNG compressors used in commercial refuelling stations has been monitored over a two year period. The output flow capacity for the compressors ranged from 0.7 - 9.62 m^3/min (25 - 340 SCFM). Operating data was collected for the total volume of natural gas used, total hours of operation & electrical energy consumption. From this data average flow rates were determined as well as the electrical energy consumption per unit volume of natural gas compressed.

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CNG COMPRESSOR OPERATIONS MONITORING

1.0 INTRODUCTION

Since 1980, compressed natural gas (CNG) has been used as an automotive fuel in Canada. CNG is stored in high pressure tanks (maximum pressure - 200 atmospheres (3000 psig)) permanently mounted in the vehicle. The tanks are refuelled by a high pressure compressor. There are two refuelling modes currently used: slow fill and fast fill. In the former, used primarily by fleet operators, the vehicle is refuelled overnight. In the latter, the vehicle is refuelled in approximately 3-5 minutes. The requirements for a CNG compressor to accomplish this are flow rates of greater than 15 SCFM and a maximum working pressure of 200 atmospheres.

This report covers the operating period between February 1986 - March 1987. Currently, there are more than ten different types of CNG compressors used in CNG refuelling stations. The operation of some of these compressors has been monitored for 13 months to determine their operating performance and is a continuation of earlier work[1]. This report presents operating field data for seven CNG compressors (six different types). In addition, information on the maintenance and reliability of each compressor has been gathered, where available. The performance of each compressor has also been compared to the manufacturer's claims.

2.0 COMPRESSORS MONITORED IN THE PRELIMINARY SURVEY

In earlier studies, seven CNG compressors had been monitored during field operation[1]. This report is a continuation of this earlier work, which has been expanded to include an additional compressor but does not include Black Top Cabs (LMF, Bauer Rix). This section describes the compressors and the type of fleets that they serve.

2.1 Norvalk CNG Compressor

The British Columbia Hydro & Power Authority has operated a Norvalk CNG compressor (Type NQ-SV3) since 1980. Currently, B.C. Hydro has a fleet of fifty vehicles which are refuelled by this compressor, usually in the slow fill mode.

The output delivery capacity (volumetric flow rate) of the compressor is advertised as 1.4 m^3/min (50 SCFM) and the maximum operating pressure is 240 atmospheres (3600 psig). B.C. Hydro limits the output pressure to 200 atm (3000 psig) to comply with the maximum working pressure of high pressure tanks used in Canada.

2.2 Ingersoll Rand CNG Compressor

B.C. Research has operated an Ingersoll Rand Model H2ONG CNG compressor since 1980. This compressor serves a fleet of approximately twenty vehicles. The majority of these vehicles are from the University of British Columbia Physical Plant fleet. In addition, three B.C. Research vehicles used for research, development and testing of CNG vehicles are refuelled by this compressor.

The output delivery capacity (volumetric flow rate) is advertised as 0.56 m^3/min (20 SCFM) and the maximum operating pressure, 240 atmospheres (3600 psig). The actual maximum operating pressure used is 200 atmospheres (3000 psig).

2.3 Idro Meccanica CNG Compressors

Presently, there are two public CNG refuelling stations in the Vancouver area which use Idro Meccanica Hydraulic compressors. These stations are operated by Husky Oil Ltd. (70th & Marine Drive, Vancouver, B.C.) and Petrocan (No. 5 Road & Steveston Highway, Richmond, B.C.). Both of these stations use Idro Meccanica CNG compressors (Model TR2 40-20-10) manufactured by CNG Fuel Systems Ltd. (Brampton, Ontario).

The compressor at the Petrocan Station is no longer monitored because fuel use was very low at this station and the compressor was identical to the unit that dispensed a much greater volume of natural gas. The majority of the vehicles served by these compressors are private vehicles or taxi-cabs.

The output delivery capacity (volumetric flow rate) is advertised as 5 m^3/min (178 SCFM) and the maximum operating pressure, 240 atmospheres (3600 psig). The actual maximum operating pressure used is 206 atmospheres (3100 psig).

2.4 Sulzer CNG Compressor

The Corporation of the District of West Vancouver has operated two Sulzer CNG compressors (Fuel Pak III D-60) since October, 1984. These two compressors fuel a fleet of about fifty vehicles. The output capacity of these compressors is rated at 1.0 m^3/min (35 SCFM).

2.5 JMAR CNG Compressor

National Energy Equipment Inc. has operated a JMAR CNG compressor (JP5-33100-6-TL) since July, 1984. This compressor is used in a public CNG refueling facility.

The output capacity of the compressor is rated at 9.6 m^3/min (340 SCFM). The compressor is operated at its maximum output pressure of 240 atm (3600 psi).

2.6 Atlas Copco CNG Compressor

Shell Canada has an Atlas Copco (L-6G) CNG compressor operating since July 1985. This is a public CNG refuelling station.

The output delivery capacity is rated at 10.4 m^3/min (295 SCFM). The maximum output pressure is 240 atmospheres (3600 psi).

2.7 LMF, Bauer and Rix CNG Compressors

Black Top and Blue Cabs Ltd. (Vancouver, B.C.) has a fleet of 130 taxis currently operating on natural gas. These taxis are filled using the fast fill mode. Until September 1985 Black Top Cabs operated four CNG compressors (1 LMF model V18D and 3 Bauer K8). The LMF has been in operation since May 1983 while the Bauer compressors have been operational since 1981.

The output delivery capacity (volumetric flow rate) of the LMF compressor is advertised as 4.06 m^3/min (145 SFFM) and the maximum operating pressure is 240 atmospheres (3600 PSIG). The Bauer K8 compressor has a rated output delivery capacity of 280 m^3/min (100 SCFM), and the maximum operating pressure is 240 atmospheres. Since September 1985, Bauer compressors No. 3 and No. 4 have been replaced by a Rix Model 2JJS 3G-98 compressor. The manufacturers' rated output is 8.78 m^3/min (310 SCFM) with a maximum operating pressure of 240 atmospheres (3600 PSIG). Since the installation of the Rix compressor the operating performance of the Black Top compressors can no longer be monitored because each compressor does not have a separate gas flow meter or watt-hr-meter. In the past with three identical Bauer units and a LMF, the flow rate was averaged assuming the flow rate of the Bauer compressors was comparable to one another. Then the average flow rate for the Bauer and LMF compressors was calculated from experimental data using a system of two equations with two unknowns. With three different compressors this is not possible since we do not have sufficient data to calculate average flow rates as we did previously.

3.0 COMPRESSOR EVALUATION METHODOLOGY

An evaluation methodology has been devised to determine the operating characteristics of CNG compressors. In this section, the various measurements required to evaluate the performance of the compressors will be described.

For the CNG compressors monitored in this study, the following data was collected where possible:

1) volume of natural gas used over a two week period (not corrected) = V_u

2) volume of natural gas used over a two week period (corrected for standard conditions) = V_c

3) hours of compressor operation over a two week period = T

4) electrical energy consumption over a two week period = E

From these measurements, the corrected and uncorrected natural gas flow rates (Q_c and Q_v) were determined using the following relations:

$$Q_c = \frac{V_c}{T} \qquad Q_u = \frac{V_u}{T} \tag{1}$$

The measured flow rate can then be compared with the expected flow rate claimed by the manufacturer. This comparison then points out the performance of the CNG compressor.

The data for the electrical energy required to operate the compressor was used together with the total hours of operation to determine the power required to operate the compressor. This data, together with the flow rate data, was also used to determine the electrical energy requirement per unit volume of natural gas compressed. This is then an indication of the efficiency of the compressor.

To summarize this section, the following data was used to monitor and compare the performance of the CNG compressors:

1) Flow rate of the compressor.

2) Ratio of measured flow rate to expected flow rate.

3) Electrical power consumption.

4) Ratio of electrical energy consumption per unit volume of natural gas compressed.

4.0 OPERATING DATA FOR SEVEN CNG COMPRESSORS

For the past 13 months operating performance data has been collected for seven (six different types) CNG compressors. The compressors monitored in this survey have been described in Section 2.0. In Section 3 the various measured quantities required to properly evaluate the operating performance of the compressors has been described. These include:

- volume of natural gas compressed (corrected and uncorrected)
- electrical energy consumption
- hours of compressor operation.

Unfortunately with some of the compressors it was not possible to obtain all this operating data. This was the case with the JMAR and the Sulzer. The operating data which could not be obtained for these compressors was the electrical energy consumption. This was due to the fact that the electric motors for these compressors did not have separate kilovatt-hour meters, and it was not possible to separate the electrical power consumption of the compressor from the total consumption of the refuelling station. The operators of the stations were asked if separate kilovatt-hour meters could be installed. Unfortunately since this required considerable down-time for the refuelling station the operators were very reluctant to do this.

Operating data for the seven CNG compressors examined in this study are given in Tables 1-6. Also included in this data are the calculated flow rates of the compressors and the ratio of electrical energy consumption per unit volume of natural gas compressed, the latter providing a measure of the efficiency of the compressor.

5.0 DISCUSSION OF RESULTS

In this section the significance of the results presented in Tables 1-6 will be briefly discussed.

5.1 Norvalk CNG Compressor

In Table 1B, the operating data for the Norvalk compressor is presented.

During the period from February 28, 1986 to March 23, 1987 the Norvalk CNG compressor dispensed 1.43×10^5 n m^3 (5.04×10^6 SCF) of natural gas. The compressor was in operation for a total of 1293 hours and used 28,120 kW-hr of electrical energy. The average flow rate of the compressor during this period was Qc = 1.84 m^3/min (65 SCFM). This is up from our earlier results which had been Qc = 1.35 m^3/min. The manufacturer claims a flow rate of 1.4 m^3/min (50 SCFM) so that this compressor operated at 130% of maximum capacity. This flow rate has increased 34% since the previous survey. It should be pointed out that B.C. Hydro made extensive changes to the compressor since the earlier data was collected. This included completely rebuilding the compressor (new pistons, etc.)

From Table 1 the average electrical power requirement was determined and found to be 21.7 kW (29 HP). As a measure of the efficiency of the compressor, that is the average electrical energy required to compress unit volume of natural gas, was found to be 1.97×10^{-1} kW-h/m^3.

5.2 Ingersoll Rand CNG Compressor

In Table 2B, the operating data for the Ingersoll Rand CNG compressor is presented for the period from February 28, 1986 to March 23, 1987. Unfortunately, during this time period the compressor has only operated for 327.8 hours, so that the performance data is very limited. The total energy consumed was 3,949 kW-hrs.

During this period, the natural gas dispensed was 1.06×10^4 m^3 (3.74×10^5 SCF). The average flow rate of the compressor during this period was $Qc = 5.4 \times 10^{-1}$ m^3/min. The manufacturer claims a flow rate of 5.6×10^{-1} m^3/min (21.3 CFM) so that this compressor operated at 96% of rated capacity during this limited cycle. This flow rate has dropped 11% since the previous survey.

The average electrical power consumed was 12.05 kW (16.2 HP), which is lower than the maximum power of the electric motor (14.9 kW) used to operate the compressor. As a measure of the efficiency of the compressor, the average electrical energy required per unit natural gas compressed was found to be 3.7×10^{-1} kW-h/m^3.

5.3 Idro Meccanica CNG Compressor

In Table 3B data for the Idro Meccanica compressor operated by Husky Oil is presented.

During the period from February 25, 1986 to March 23, 1987 the Husky Oil Idro Meccanica compressor dispensed 8.20×10^5 m^3 (2.89×10^7 SCF) of natural gas. The compressor was in operation for a total of 3,493.7 hours and used 21,132 kW-hr of electrical energy. The average flow rate of the compressor during this period was $Q_c = 3.91$ m^3/min (138 SCFM). The average electrical power consumed was 6.04 kW (8.1 hp). The manufacturer claims a flow rate of 4.98 m^3 (176 SCFM), so that this

compressor operated at 78% of its rated capacity. This was the lowest observed performance (i.e. ratio of measured flow rate to rated output) of any of the compressors monitored in this study, although it has increased 9% since the last survey.

As a measure of the efficiency of the compressor, that is the average electrical energy required to compress unit volume of natural gas, was found to be 2.58×10^{-1} kW-h/m^3.

5.4 Sulzer CNG Compressor

In Table 4B the operating data for the two Sulzer compressors is presented. During the period from March 17, 1986 to March 9, 1987, the two Sulzer compressors dispensed 1.14×10^5 m^3 (4.02×10^6 SCF), and to do this the compressors were operated for 964.4 and 960.2 hours respectively. The average flow rate for each compressor was calculated to be 0.99 m^3/min (34.95 SCFM). The manufacturer claims a flow rate of 1.0 m^3/min (35.3 SCFM), so that these compressors operated at 99% of their rated output. This flow rate has increased 3% since the last survey. The average power requirement and efficiency of these compressors could not be determined since a watt-hour meter was not included in the installation.

5.5 JMAR CNG Compressor

In Table 5B the operating data for the JMAR compressor is presented. During the period from August 11, 1986 to March 23, 1987 the JMAR compressor dispensed 2.83×10^5 m^3 (1.71×10^7 SCF) of natural gas, operating over 641.1 hours. The average flow rate of the compressor during this period was 6.88 m^3/min (259.9 SCFM). The manufacturer claims a flow rate of 9.62 m^3/min (340 SCFM), so that this compressor operated at only 76% of its rated output. This flow rate is up 4% from the previous survey.

5.6 Atlas Copco CNG Compressor

On Table 6 the operating data for the Atlas Copco Model L-6G is presented.

During the period of April 22, 1986 to March 23, 1987 the Atlas Copco compressor dispensed 7.18 x 10^5 m^3 (2.53 x 10^7 SCF) of natural gas, operating over 1823 hours and consuming 17,304 kW-hrs of energy. The average flow rate of the compressor during this period was Q_c = 6.56 m^3/min (232 SCFM). The manufacturer claims a flow rate of 8.36 m^3/min (295 SCFM) so this compressor operated at only 77% of its rated output.

From Table 6 the average electrical power requirement was determined and found to be 9.49 kW (12.8 hp). As a measure of the efficiency of the compressor the average electrical energy required to compress unit volume of natural gas was found to be 2.41 x 10^{-1} Kw-h/m^3.

6.0 MAINTENANCE AND RELIABILITY OF THE CNG COMPRESSORS

During the course of this compressor monitoring study, we were able to gather some information on the maintenance and reliability of the compressors. In this section the operating experience regarding reliability and durability is briefly summarized.

6.1 Norwalk

During 1985 B.C. Hydro performed a major overhaul of their compressor. The compressor was dismantled and the pistons replaced. In addition the cylinder heads were rebuilt. During the operating period of this survey the compressor had a problem with valves carbonizing caused by the lubricator pumping excessive amounts of oil. B.C. Hydro modified the lubricator to overcome this problem.

6.2 Ingersoll Rand

The Ingersoll Rand Compressor operated by B.C. Research has had no major problems since the electric motor was rebuilt in December 1980 (although oil consumption is up and efficiency is down). A high pressure gas leak under the head of the fourth stage was repaired by replacing the copper sealing gasket. The fourth stage valve was removed and was noticed to be sticking. New valve springs were installed.

6.3 Idro Meccanica

The Idro Meccanica compressor monitored in the previous survey experienced considerable reliability problems. The major problem area was the forward/reverse transmission (manufactured by Volvo) which was continuously breaking down and needed maintenance. Recently a computer control system designed to dampen the forward-reverse action of the transmission was installed and the problem since has been solved. The owner of the Husky Station is now pleased with the operation of the compressor.

6.4 Sulzer

During the first survey the Sulzer CNG compressors, which are operated by the district of West Vancouver, had not been operated for a long enough time period to make any meaningful comments regarding reliability. Over the last sixteen months some problems have developed. There have been some problems with water in the oil trap, causing it to freeze up in cold weather. This resulted in the high oil pressure switch being actuated, which should not have occurred. In addition this compressor station has had problems with the sequential fill panel.

6.5 JMAR

Information on the reliability of the JMAR CNG compressor which is operated by National Energy was not provided by the operator even though we requested this data. Therefore we can not comment on its reliability. During the period of this survey the operator concluded that the compressor was running above normal operating temperatures. This problem was solved by installing a larger air intake inlet.

6.6 Atlas Copco

The Atlas Copco Compressor operated by Shell Canada has had a few minor problems since the beginning of this survey. The most serious being a faulty "O" ring on the coolant side of the aftercooler causing coolant, and later high pressure gas to vent. Other minor problems included gas leaking from shut off valves at the cascade, and low oil pressure in the compressor.

7.0 SUMMARY

Seven high pressure CNG compressors (six different types) have been monitored over a period of one year to determine their operating performance. The measured flow rate was determined for each compressor and compared to their rated output. Half of the compressors operated close to their rated output (i.e. 90% or greater than rated flow capacity), as shown below.

1)	Norvalk	130%
2)	Ingersoll Rand	96%
3)	Idro Meccanica	78%
4)	Sulzer (2)	99%
5)	JMAR	76%
6)	Atlas Copco	77%

It should be noted that most of these compressors increased their flow rate over the earlier survey. This is probably due to a higher duty cycle for the compressors, which results in the compressors operating for more time at optimum operating temperatures.

The efficiency of each compressor was determined by measuring the electrical power consumption when data was available and the total natural gas dispensed by each compressor. From this, the electrical energy required to compress unit volume of natural gas was determined and is given below:

1) Norvalk $1.97 \times 10^{-1} \frac{kW\text{-}h}{m^3}$

2) Ingersoll Rand $3.7 \times 10^{-1} \frac{kW\text{-}h}{m^3}$

3) Idro Meccanica (Husky Oil) $2.58 \times 10^{-1} \frac{kW\text{-}h}{m^3}$

4) Atlas Copco $2.41 \times 10^{-1} \frac{kW\text{-}h}{m^3}$

During this monitoring program there have been some significant improvements in compressor reliability, most notably with the Idro Meccanica. In general it appears that all the compressors are exhibiting good reliability with their major mechanical components. Minor problems (gas leaks, oil leaks, etc.) are still encountered but do not appear to severely hamper (excessive down-time) the operation of the refuelling station.

8.0 REFERENCES

1. CNG Compressor Operations Monitoring, B.C. Research Report 4-09-248, June 1983.

2. CNG Compressor Operations Monitoring, B.C. Research Report, January 1986.

TABLES

TABLE 1A
OPERATING DATA FOR THE NORVALK CNG COMPRESSOR
(B.C. HYDRO)

DATE	VOL (m^3)	VOL ($n\ m^3$)	ENER/VOL (kW-HR/$n\ m^3$)	HOURS	FL. RATE (SCFM)	FL. RATE ($n\ m^3$/min)
Mar 12 84	314.4	3.88×10^3	1.91×10^{-1}	42.4	53.9	1.5
Mar 19 84	484.3	5.98	1.93	65.6	53.6	1.5
Apr 02 84	761.8	9.40	1.94	103.4	53.5	1.5
Apr 16 84	1076.2	1.33×10^4	1.93	145.5	53.8	1.5
Apr 30 84	1319.7	1.63	1.92	177.7	54.1	1.5
May 14 84	1639.8	2.03	1.89	218.8	54.6	1.5
May 28 84	1883.3	2.33	1.88	249.4	55.0	1.6
Jun 08 84	2090.1	2.59	1.87	275.7	55.3	1.6
Jun 25 84	2313.8	2.86	1.87	304.0	55.4	1.6
Jul 09 84	2378.9	2.95	1.87	313.1	55.4	1.6
Jul 23 84	2560.2	3.17	1.89	342.1	54.6	1.5
Aug 07 84	2752.8	3.42	1.92	373.4	53.8	1.5
Aug 20 84	2894.4	3.42	2.03	395.6	50.9	1.4
Sep 04 84	3112.4	3.87	1.95	429.5	53.0	1.5
Sep 17 84	3373.0	4.19	1.97	470.2	52.5	1.5
Oct 01 84	3673.2	4.57	2.00	521.3	51.6	1.5
Oct 15 84	3942.2	4.90	2.03	565.8	51.0	1.4
Oct 29 84	4318.9	5.37	2.07	629.1	50.2	1.4
Nov 13 84	4704.1	5.84	2.11	694.1	49.5	1.4
Nov 26 84	5041.1	6.25	2.14	750.5	49.0	1.4
Dec 10 84	5375.2	6.66	2.16	807.4	48.5	1.4
Dec 24 84	5633.0	6.97	2.19	853.4	48.1	1.4
Jan 08 85	5785.9	7.15	2.20	881.1	47.8	1.4
Jan 20 85	6193.7	7.65	2.23	953.8	47.2	1.3
Feb 04 85	6516.6	8.04	2.27	1026.9	46.1	1.3
Feb 18 85	6796.9	8.38	2.31	1098.6	44.9	1.3
Mar 04 85	7122.6	8.78	2.36	1188.0	43.5	1.2
Mar 18 85	7434.2	9.16	2.41	1272.5	42.4	1.2
Apr 02 85	7822.1	9.63	2.41	1338.9	42.3	1.2
Apr 15 85	8102.5	9.98	2.41	1383.8	42.4	1.2
Apr 29 85	8448.0	1.04×10^5	2.40	1439.6	42.5	1.2
May 21 85	8949.3	1.10	2.40	1520.1	42.7	1.2
Jun 03 85	9221.2	1.14	2.39	1562.9	42.8	1.2
Jun 24 85	9759.3	1.20	2.39	1652.6	42.9	1.2
Jul 08 85	10011.3	1.24	2.39	1696.0	42.9	1.2
Jul 22 85	10280.4	1.27	2.39	1739.4	42.9	1.2
Aug 07 85	10600.4	1.31	2.38	1773.3	43.3	1.2
Aug 19 85	10824.1	1.33	2.37	1795.7	43.7	1.2
Sep 03 85	11178.1	1.38	2.36	1832.6	44.2	1.3
Sep 16 85	11535.0	1.42	2.34	1870.5	44.7	1.3
Sep 30 85	11951.3	1.47	2.33	1915.3	45.3	1.3
Oct 15 85	12489.4	1.54	2.31	1972.4	46.0	1.3
Oct 28 85	12908.5	1.59	2.29	2017.2	46.4	1.3
Nov 12 85	13387.1	1.65	2.28	2068.5	47.0	1.3
Nov 25 85	13789.3	1.70	2.27	2112.2	47.3	1.3
Dec 09 85	14219.8	1.75	2.27	2160.1	47.7	1.3

TABLE 1B
OPERATING DATA FOR THE NORVALK CNG COMPRESSOR
(B.C. HYDRO)

DATE	VOL (m^3)	VOL ($n\ m^3$)	ENER/VOL (kW-HR/$n\ m^3$)	HOURS	FL. RATE (SCFM)	FL. RATE ($n\ m^3$/min)
Mar 17 86	14885.3	1.83×10^5	2.26×10^{-1}	2231.1	48.3	1.4
Apr 01 86	15346.9	1.89	2.25	2281.1	48.7	1.4
Apr 14 86	15771.7	1.94	2.25	2327.8	49.1	1.4
Apr 28 86	16239.0	2.00	2.24	2378.6	49.4	1.4
May 12 86	16723.3	2.06	2.23	2434.2	49.7	1.4
May 26 86	17148.1	2.11	2.23	2483.5	50.0	1.4
Jun 09 86	17572.9	2.16	2.22	2533.8	50.3	1.4
Jul 02 86	18176.2	2.24	2.21	2604.0	50.6	1.4
Jul 14 86	18459.4	2.27	2.21	2637.4	50.8	1.4
Jul 28 86	18813.4	2.32	2.21	2681.7	50.9	1.4
Aug 11 86	19153.2	2.36	2.21	2723.3	51.0	1.4
Aug 25 86	19481.7	2.40	2.20	2762.5	51.1	1.4
Sep 08 86	19815.9	2.44	2.20	2803.2	51.3	1.5
Sep 22 86	20203.9	2.49	2.20	2850.9	51.4	1.5
Oct 06 86	20549.4	2.53	2.20	2894.4	51.5	1.5
Oct 20 86	20824.1	2.57	2.20	2931.5	51.5	1.5
Nov 03 86	21212.1	2.62	2.19	2972.0	51.8	1.5
Nov 17 86	21636.9	2.67	2.19	3016.5	52.0	1.5
Dec 01 86	22073.1	2.72	2.18	3061.6	52.3	1.5
Dec 15 86	22472.4	2.77	2.17	3104.5	52.5	1.5
Jan 05 87	23021.8	2.84	2.17	3162.2	52.8	1.5
Jan 26 87	23933.7	2.95	2.15	3256.3	53.3	1.5
Feb 09 87	24494.5	3.02	2.15	3311.8	53.6	1.5
Feb 23 87	25001.4	3.08	2.14	3361.6	53.9	1.5
Mar 09 87	25420.6	3.13	2.14	3409.9	54.0	1.5
Mar 23 87	25791.6	3.18	2.13	3452.7	54.1	1.5

TABLE 2A
OPERATING DATA FOR THE INGERSOLL RAND CNG COMPRESSOR
(B.C. RESEARCH)

DATE	VOL (m^3)	ENER/VOL ($kW\text{-}HR/m^3$)	HOURS	FL. RATE (SCFM)	FL. RATE (m^3/min)
May 28 84	4.96×10^2	3.74×10^{-1}	13.7	21.29	0.60
Jun 08 84	8.78	3.70	26.3	19.64	0.56
Jun 25 84	1.17	3.77	33.0	20.86	0.59
Jul 09 84	1.25×10^3	3.68	34.1	21.65	0.61
Jul 23 84	1.40	3.65	37.0	22.21	0.63
Aug 07 84	1.59	3.71	41.4	22.58	0.64
Aug 20 84	1.80	3.61	47.6	22.30	0.63
Sep 04 84	2.36	3.62	54.4	25.49	0.72
Sep 17 84	2.35	3.59	63.4	21.82	0.62
Oct 01 84	2.58	3.58	69.1	21.95	0.62
Oct 15 84	2.73	3.57	72.1	22.28	0.63
Nov 13 84	3.03	3.56	77.7	22.93	0.65
Nov 26 84	3.18	3.57	80.3	23.33	0.66
Dec 10 84	3.59	3.58	92.2	22.94	0.65
Dec 24 84	3.83	3.56	98.1	22.95	0.65
Jan 08 85	4.03	3.63	103.0	23.04	0.65
Jan 21 85	4.39	3.62	114.1	22.66	0.64
Feb 04 85	4.80	3.62	126.6	22.33	0.63
Feb 18 85	5.01	3.61	131.8	22.38	0.63
Mar 04 85	5.35	3.61	141.3	22.28	0.63
Mar 18 85	5.75	3.60	153.7	22.00	0.62
Apr 02 85	6.16	3.60	166.5	21.76	0.62
Apr 15 85	6.36	3.60	171.8	21.78	0.62
Apr 29 85	6.80	3.58	186.1	21.50	0.61
May 21 85	7.56	3.57	210.3	21.15	0.60
Jun 03 85	7.91	3.56	221.1	21.05	0.60
Jun 24 85	8.49	3.54	239.3	20.88	0.59
Jul 08 85	8.78	3.53	248.9	20.76	0.59
Jul 22 85	9.20	3.52	262.8	20.61	0.58
Aug 07 85	9.81	3.52	283.5	20.37	0.58
Aug 19 85	1.02	3.52	295.7	20.26	0.57
Sep 03 85	1.02×10^4	3.52	295.7	20.26	0.57
Sep 16 85	1.03	3.52	297.7	20.42	0.58
Sep 30 85	1.04	3.52	301.1	20.39	0.58
Oct 15 85	1.08	3.52	309.7	20.45	0.58
Oct 28 85	1.11	3.52	319.7	20.45	0.58
Nov 12 85	1.17	3.61	338.4	20.37	0.58
Nov 25 85	1.22	3.53	350.6	20.47	0.58
Dec 09 85	1.22	3.54	351.2	20.50	0.58

TABLE 2B
OPERATING DATA FOR THE INGERSOLL RAND CNG COMPRESSOR

DATE	VOL (m^3)	ENER/VOL ($kW\text{-}HR/m^3$)	HOURS	FL. RATE (SCFM)	FL. RATE (m^3/min)
Mar 17 86	1.24×10^4	3.54×10^{-1}	365.4	20.04	0.57
Apr 01 86	1.26	3.54	370.1	20.04	0.57
Apr 14 86	1.28	3.55	375.7	20.02	0.57
Apr 28 86	1.31	3.54	383.6	20.06	0.57
May 12 86	1.37	3.53	402.8	20.00	0.57
May 26 86	1.41	3.53	413.2	20.02	0.57
Jul 02 86	1.46	3.53	427.5	20.16	0.57
Jul 14 86	1.49	3.53	434.4	20.19	0.57
Aug 11 86	1.52	3.53	441.0	20.31	0.58
Aug 25 86	1.55	3.52	449.4	20.32	0.58
Sep 08 86	1.61	3.51	467.2	20.29	0.57
Sep 22 86	1.65	3.50	479.7	20.29	0.57
Oct 06 86	1.68	3.50	487.8	20.28	0.57
Nov 03 86	1.74	3.49	504.9	20.33	0.58
Nov 17 86	1.78	3.49	513.8	20.35	0.58
Dec 01 86	1.84	3.49	534.5	20.25	0.57
Jan 05 87	1.95	3.48	568.7	20.17	0.57
Jan 26 87	2.03	3.48	595.7	20.07	0.57
Feb 09 87	2.17	3.48	640.4	19.91	0.56
Mar 13 87	2.24	3.48	665.9	19.84	0.56
Mar 23 87	2.27	3.48	675.6	19.81	0.56

TABLE 3A
OPERATING DATA FOR THE IDRO MECCANICA CNG COMPRESSOR
(HUSKY OIL)

DATE	VOL (m^3)	VOL ($n\ m^3$)	ENER/VOL (kW-HR/$n\ m^3$)	HOURS	FL. RATE (SCFM)	FL. RATE ($n\ m^3$/min)
Mar 12 84	1274.4	6.37×10^3	2.82×10^{-1}	28.8	130.2	3.7
Mar 19 84	2766.9	1.38×10^4	2.78	61.9	131.4	3.7
Apr 02 84	5511.2	2.76	2.74	123.3	131.5	3.7
Apr 16 84	9073.9	4.53	2.70	202.5	131.8	3.7
Apr 30 84	12302.5	6.15	2.73	283.6	127.6	3.6
May 14 84	16023.8	8.01	2.71	361.9	130.3	3.7
May 28 84	19504.4	9.76	2.69	435.8	131.8	3.7
Jun 08 84	23160.6	1.16×10^5	2.68	512.1	133.2	3.8
Jun 25 84	28300.8	1.42	2.67	626.2	133.1	3.8
Jul 09 84	32520.5	1.63	2.65	709.8	135.0	3.8
Jul 23 84	37201.9	1.86	2.62	805.1	136.1	3.9
Aug 07 84	41339.6	2.07	2.60	891.6	136.6	3.9
Aug 20 84	45284.6	2.27	2.60	978.6	136.3	3.9
Sep 04 84	50068.0	2.51	2.63	1100.9	134.0	3.8
Sep 17 84	54585.1	2.73	2.62	1204.4	133.6	3.8
Oct 01 84	59056.9	2.96	2.64	1335.5	130.4	3.7
Oct 15 84	63432.5	3.18	2.64	1440.1	129.9	3.7
Oct 29 84	67547.4	3.38	2.64	1535.6	129.7	3.7
Nov 13 84	71903.1	3.60	2.64	1640.5	129.1	3.7
Nov 26 84	75695.3	3.79	2.64	1744.8	127.7	3.6
Dec 24 84	84735.2	4.23	2.64	1954.0	127.4	3.6
Jan 08 85	88079.9	4.39	2.64	2024.5	127.8	3.6
Jan 20 85	92594.2	4.62	2.64	2122.6	128.0	3.6
Feb 04 85	97459.6	4.86	2.66	2230.3	128.2	3.6
Feb 18 85	102415.7	5.10	2.64	2349.7	127.8	3.6
Mar 04 85	107250.1	5.34	2.64	2455.7	128.0	3.6
Mar 18 85	112554.5	5.60	2.63	2565.9	128.5	3.6
Apr 02 85	118558.5	5.90	2.62	2690.5	129.1	3.7
Apr 15 85	123738.3	6.16	2.62	2809.3	129.0	3.7
Apr 29 85	128453.7	6.39	2.62	2914.5	129.1	3.7
May 21 85	136746.0	6.81	2.65	3144.9	127.4	3.6
Jun 03 85	141430.2	7.04	2.68	3308.9	125.2	3.5
Jun 24 85	150096.3	7.47	2.68	3549.1	123.9	3.5
Jul 08 85	154854.1	7.71	2.68	3669.0	123.7	3.5
Jul 22 85	159555.4	7.95	2.67	3772.4	124.0	3.5
Aug 07 85	166451.4	8.29	2.66	3934.9	124.0	3.5
Aug 19 85	171090.4	8.53	2.66	4042.4	124.1	3.5
Sep 03 85	176915.9	8.82	2.66	4182.7	124.1	3.5
Sep 16 85	182378.9	9.10	2.66	4330.2	123.7	3.5
Sep 30 85	188218.6	9.39	2.66	4502.4	122.7	3.5
Oct 15 85	193896.9	9.67	2.66	4635.4	122.8	3.5
Oct 28 85	199280.7	9.94	2.65	4761.3	122.9	3.5
Nov 12 85	204896.6	1.02×10^6	2.66	4905.5	122.6	3.5
Nov 25 85	209742.3	1.05	2.66	5020.4	122.6	3.5
Dec 09 85	214454.8	1.07	2.66	5122.5	122.8	3.5

TABLE 3B
OPERATING DATA FOR THE IDRO MECCANICA CNG COMPRESSOR
(HUSKY OIL)

DATE	VOL (m^3)	VOL ($n\ m^3$)	ENER/VOL ($kW\text{-}HR/n\ m^3$)	HOURS	FL. RATE (SCFM)	FL. RATE ($n\ m^3/min$)
Mar 17 86	222888.7	1.11×10^6	2.67×10^{-1}	5313.2	123.1	3.5
Apr 01 86	229444.9	1.14	2.66	5457.4	123.3	3.5
Apr 14 86	234709.7	1.17	2.67	5566.8	123.7	3.5
Apr 28 86	241155.5	1.20	2.67	5702.7	123.3	3.5
May 12 86	247227.4	1.23	2.65	5829.8	124.4	3.5
May 26 86	253350.3	1.26	2.65	5958.0	124.8	3.5
Jun 09 86	259563.9	1.29	2.64	6093.2	125.0	3.5
Jul 02 86	269538.4	1.34	2.64	6318.1	125.2	3.5
Jul 14 86	274797.5	1.37	2.64	6434.5	125.4	3.6
Jul 28 86	280869.5	1.40	2.65	6575.2	125.4	3.6
Aug 11 86	286692.1	1.43	2.64	6691.0	125.8	3.6
Aug 25 86	293072.8	1.46	2.64	6819.3	126.2	3.6
Sep 08 86	299255.2	1.51	2.61	6952.4	127.6	3.6
Sep 22 86	305972.8	1.53	2.63	7085.2	126.8	3.6
Oct 06 86	312670.6	1.56	2.63	7229.3	127.0	3.6
Oct 20 86	318722.7	1.59	2.63	7350.6	127.3	3.6
Nov 03 86	324854.1	1.62	2.62	7477.0	127.6	3.6
Nov 17 86	330923.3	1.65	2.62	7603.3	127.8	3.6
Dec 01 86	337533.3	1.68	2.62	7739.5	128.1	3.6
Dec 15 86	344208.5	1.72	2.62	7877.4	128.3	3.6
Jan 05 87	351552.0	1.75	2.62	8031.4	128.5	3.6
Feb 09 87	364386.9	1.82	2.62	8300.2	128.9	3.6
Feb 23 87	369657.3	1.84	2.62	8411.0	129.0	3.7
Mar 09 87	374678.5	1.87	2.62	8519.1	129.1	3.7
Mar 23 87	379512.9	1.89	2.62	8616.2	129.3	3.7

TABLE 4A
OPERATING DATA FOR THE JHAR CNG COMPRESSOR
(NATIONAL ENERGY)

DATE	TOTAL VOL (CF)	TOTAL VOL (m^3)	HOURS CO. A	HOURS CO. B	AV. FLOW EACH CO. (CFM)	AV. FLOW EACH CO. (m^3/min)
Nov 13 84	1.61×10^5	4.55×10^3	42.6	12.2	48.9	1.39
Nov 26 84	2.95	8.34	82.6	36.9	41.1	1.16
Dec 10 84	4.42	1.25×10^4	110.2	79.3	38.9	1.10
Jan 08 85	6.42	1.82	155.7	129.9	37.5	1.06
Jan 20 85	7.59	2.15	184.0	158.2	37.0	1.05
Feb 04 85	7.65	2.17	218.0	191.9	31.1	0.88
Feb 18 85	8.95	2.54	249.6	223.5	31.5	0.89
Mar 04 85	1.18×10^6	3.33	285.9	259.7	35.9	1.02
Mar 18 85	1.33	3.78	324.0	297.8	35.8	1.01
Apr 02 85	1.37	3.87	362.6	336.4	32.6	0.92
Apr 15 85	1.51	4.28	396.1	369.9	32.9	0.93
Apr 29 85	1.68	4.76	436.1	409.8	33.1	0.94
May 21 85	1.93	5.47	494.3	467.9	33.4	0.95
Jun 03 85	2.07	5.86	527.5	501.0	33.5	0.95
Jun 24 85	2.32	6.57	587.1	560.4	33.7	0.95
Jul 08 85	2.49	7.06	628.5	601.9	33.8	0.96
Jul 22 85	2.67	7.56	672.2	645.6	33.8	0.96
Aug 07 85	2.86	8.11	719.5	692.9	33.8	0.96
Aug 19 85	3.01	8.53	754.9	728.3	33.8	0.96
Sep 03 85	3.21	9.10	803.3	776.6	33.9	0.96
Sep 16 85	3.40	9.63	847.6	820.9	34.0	0.96
Sep 30 85	3.62	1.02×10^5	898.2	871.4	34.1	0.96
Oct 15 85	3.83	1.09	948.8	922.0	34.2	0.97
Oct 28 85	4.02	1.14	997.6	966.4	34.1	0.97
Nov 12 85	4.26	1.21	1061.0	1026.3	34.0	0.96
Nov 25 85	4.50	1.27	1109.1	1076.4	34.3	0.97
Dec 09 85	4.71	1.33	1159.5	1114.1	34.5	0.98

TABLE 4B
OPERATING DATA FOR THE JMAR CNG COMPRESSOR
(NATIONAL ENERGY)

DATE	TOTAL VOL (CF)	TOTAL VOL (m^3)	HOURS CO. A	HOURS CO. B	AV. FLOW EACH CO. (CFM)	AV. FLOW EACH CO. (m^3/min)
Mar 17 86	$6.09X10^6$	$1.72x10^5$	1535.8	1337.9	35.3	1.00
Apr 01 86	6.29	1.78	1576.3	1388.9	35.4	1.00
Apr 14 86	6.48	1.84	1602.4	1444.7	35.4	1.00
Apr 28 86	6.68	1.89	1635.9	1501.8	35.5	1.01
May 12 86	6.86	1.94	1676.0	1541.9	35.5	1.01
May 26 86	7.01	1.98	1711.1	1577.0	35.5	1.01
Jun 09 86	7.17	2.03	1749.3	1615.0	35.5	1.01
Jul 02 86	7.43	2.10	1812.1	1677.9	35.5	1.00
Jul 14 86	7.55	2.14	1839.4	1704.4	35.5	1.00
Jul 28 86	7.69	2.18	1881.3	1730.2	35.5	1.01
Aug 11 86	7.82	2.21	1916.0	1755.5	35.5	1.01
Aug 25 86	7.95	2.25	1954.4	1780.6	35.5	1.00
Sep 08 86	8.05	2.28	1990.4	1791.2	35.5	1.00
Sep 22 86	8.18	2.32	2022.1	1817.5	35.5	1.01
Oct 06 86	8.33	2.36	2067.6	1842.5	35.5	1.01
Oct 20 86	8.46	2.40	2103.2	1869.1	35.5	1.01
Nov 03 86	8.61	2.44	2142.6	1899.2	35.5	1.01
Nov 17 86	8.78	2.49	2184.3	1931.7	35.5	1.01
Dec 01 86	8.96	2.54	2201.0	1999.4	35.5	1.01
Dec 15 86	9.15	2.59	2209.5	2082.4	35.5	1.01
Jan 05 87	9.31	2.64	2211.8	2155.1	35.5	1.01
Jan 26 87	9.57	2.17	2229.3	2264.8	35.5	1.01
Feb 09 87	9.73	2.76	2292.3	2274.6	35.5	1.01
Feb 23 87	9.92	2.81	2366.2	2288.8	35.5	1.01
Mar 09 87	1.01	2.86	2434.1	2295.3	35.5	1.01

TABLE 5A
OPERATING DATA FOR THE SULZER CNG COMPRESSOR
(DISTRICT OF WEST VANCOUVER)

DATE	VOL (m^3)	VOL ($n\ m^3$)	HOURS	FL. RATE (SCFM)	FL. RATE ($n\ m^3/min$)
Nov 13 84	81.8	6.09×10^3	14.7	243.8	6.9
Nov 26 84	173.6	1.29×10^4	31.1	244.4	6.9
Dec 10 84	311.8	2.31	55.5	245.3	6.9
Dec 24 84	432.2	3.20	77.1	244.3	6.9
Jan 08 85	501.8	3.71	89.7	243.6	6.9
Jan 20 85	644.6	4.77	117.0	240.0	6.8
Feb 04 85	806.6	5.96	147.5	238.0	6.7
Feb 18 85	995.8	7.36	181.6	238.4	6.8
Mar 04 85	1221.8	9.02	222.7	238.4	6.8
Mar 18 85	1469.6	1.09×10^5	267.2	239.1	6.8
Apr 02 85	1799.2	1.33	325.2	240.5	6.8
Apr 15 85	2054.4	1.52	370.9	240.6	6.8
Apr 29 85	2337.9	1.73	421.1	241.2	6.8
May 21 85	2790.7	2.06	501.4	241.8	6.8
Jun 03 85	3077.0	2.27	552.5	241.9	6.8
Jun 24 85	3561.9	2.63	639.4	241.8	6.8
Jul 08 85	3785.0	2.79	679.7	241.8	6.8
Jul 22 85	4061.5	3.00	730.1	241.5	6.8
Aug 07 85	4363.6	3.22	783.8	241.8	6.8
Aug 19 85	4538.9	3.35	814.9	241.9	6.9
Sep 03 85	4757.3	3.51	853.6	242.1	6.9
Sep 16 85	4987.8	3.68	894.9	242.2	6.9
Sep 30 85	5256.3	3.88	941.0	242.4	6.9
Oct 15 85	5543.8	4.08	990.9	242.3	6.9
Oct 28 85	5784.5	4.26	1034.1	242.4	6.9
Nov 12 85	6069.4	4.47	1085.2	242.4	6.9
Nov 25 85	6367.6	4.69	1138.9	242.4	6.9
Dec 09 85	6672.9	4.92	1192.7	242.6	6.9

TABLE 5B
OPERATING DATA FOR THE SULZER COMPRESSOR
(DISTRICT OF WEST VANCOUVER)

DATE	VOL (m^3)	VOL ($n\ m^3$)	HOURS	FL. RATE (SCFM)	FL. RATE ($n\ m^3$/min)
Aug 25 86	6940.6	5.11×10^5	1238.4	243.1	6.9
Sep 08 86	7195.5	5.29	1278.8	243.5	6.9
Sep 22 86	7450.4	5.49	1325.1	244.0	6.9
Oct 06 86	7733.7	5.70	1371.8	244.5	6.9
Oct 20 86	7988.7	5.88	1413.7	244.9	6.9
Nov 03 86	8243.6	6.08	1458.4	245.3	6.9
Nov 17 86	8498.6	6.27	1500.3	245.8	7.0
Dec 01 86	8753.5	6.46	1544.0	246.2	7.0
Dec 15 86	9036.8	6.66	1589.4	246.6	7.0
Jan 05 87	9348.4	6.89	1641.5	247.0	7.0
Jan 26 87	9716.7	7.17	1705.3	247.5	7.0
Feb 09 87	9971.7	7.36	1747.2	247.8	7.0
Feb 23 87	10226.6	7.55	1791.5	248.1	7.0
Mar 09 87	10509.9	7.74	1834.7	248.4	7.0

TABLE 6
OPERATING DATA FOR THE ATLAS COPCO COMPRESSOR (SHELL)

DATE	VOL (m^3)	VOL ($n\ m^3$)	ENER/VOL ($kW\text{-}HR/n\ m^3$)	HOURS	FL. RATE (SCFM)	FL. RATE ($n\ m^3/min$)
Apr 28 86	3078.4	1.51×10^4	1.19×10^{-1}	40.8	217.7	6.2
May 12 86	9994.3	4.93	1.19	131.8	220.2	6.2
May 27 86	16983.9	8.41	1.18	224.1	220.9	6.3
Jun 09 86	23067.1	1.15×10^5	1.18	304.2	221.9	6.3
Jul 02 86	33370.1	1.66	1.18	439.8	222.8	6.3
Jul 28 86	44672.9	2.23	1.18	589.2	223.0	6.3
Aug 11 86	50637.2	2.53	1.18	668.3	223.1	6.3
Aug 25 86	58841.7	2.87	1.18	756.3	223.3	6.3
Sep 08 86	63211.6	3.17	1.17	835.0	223.2	6.3
Sep 22 86	69229.7	3.47	1.18	915.7	222.9	6.3
Oct 06 86	75075.1	3.76	1.18	987.1	224.1	6.3
Oct 20 86	81265.9	4.06	1.18	1057.8	226.1	6.4
Nov 03 86	87499.3	4.37	1.17	1129.1	227.9	6.5
Nov 17 86	93763.8	4.67	1.17	1198.1	229.6	6.5
Dec 01 86	100266.2	4.99	1.17	1269.3	231.3	6.6
Dec 15 86	107442.7	5.33	1.17	1347.1	232.9	6.6
Jan 05 87	115066.6	5.70	1.17	1431.3	234.3	6.6
Jan 26 87	123837.4	6.12	1.18	1542.3	233.3	6.6
Feb 09 87	130062.3	6.42	1.19	1615.1	233.8	6.6
Feb 23 87	136244.7	6.72	1.21	1717.1	230.3	6.5
Mar 09 87	142489.4	7.02	1.21	1790.8	230.8	6.5
Mar 23 87	148759.6	7.33	1.20	1863.9	231.4	6.6